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EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG

David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS

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Dominion Astronomer
Ottawa

J. A. PEARCE
Head Astronomer
Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

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Vol. XXXIX, No. 1 JANUARY, 1945 Whole No. 340

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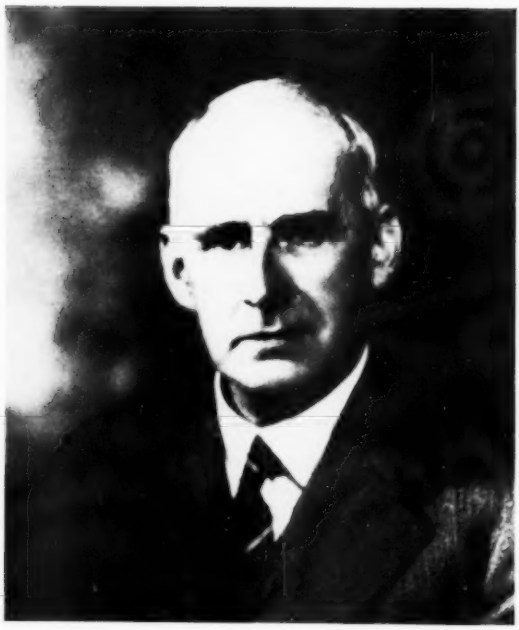
PLATE I



SIR ARTHUR STANLEY EDDINGTON
(1882-1944)

(Photograph by Lafayette, Ltd., supplied by courtesy of Harvard Observatory.)

THE JOURNAL

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THE ROYAL ASTRONOMICAL SOCIETY
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VOL. XXXIX, No. 1 JANUARY, 1945 WHOLE No. 340

ARTHUR STANLEY EDDINGTON

By A. VIBERT DOUGLAS

President of the Royal Astronomical Society of Canada

(With Plate I)

TO the memory of a great and good man, Sir Arthur Stanley Eddington, O.M., F.R.S., and in recognition of his contributions to physical science and to philosophy, the Royal Astronomical Society of Canada pays its tribute.

Had Sir Arthur lived until the Annual Meeting of this society in January 1945, he would have been one of the first two Honorary Members of the R.A.S.C. to be elected under its new Constitution. The committee charged with the selection of Honorary Members placed his name before General Council in the following terms:

We nominate for honorary membership—

Sir Arthur Stanley Eddington, O.M., M.A., D.Sc., LL.D., F.R.S.
Plumian Professor of Astronomy in the University of Cambridge.

Sir Arthur Eddington has been contributing to the progress of astronomy and cosmology for about forty years in fields as diverse as stellar movements, internal constitution of the stars, (radiation pressure, pulsating stars, stellar diameters and densities, white dwarfs, central temperatures), mathematical theory of relativity, cosmological and physical constants, combination of relativity and quantum theories. His papers before the Royal Society, The Royal Astronomical Society and other national and international scientific bodies have placed him in the very forefront of the world's scientists. His expositions in *The Nature of the Physical World*, *New Pathways of Science*, *The Philosophy of Physical Science*, have been stimulating to scientists, philosophers, metaphysicians and thinking laymen in many countries. His insight and powerful thinking have placed his work at the foundations and within the superstructures of many investigations still in progress. We are proposing an honour to our R.A.S.C. in suggesting that Sir Arthur Eddington be asked to accept honorary membership.

In 1882 Eddington was born in Kendal, Westmorland. From Owens College, Manchester, he went to Cambridge where he became Senior Wrangler and Smith's Prizeman, Fellow of Trinity, F.R.S., Plumian Professor and Director of Cambridge Observatory, before he was thirty-two. During seven of these years he was Chief Assistant at Greenwich and concentrated on investigation of stellar movements, star streaming, and the structure of the galaxy, devising an effective way of projecting proper motions in different regions of the celestial sphere so that general trends would emerge.

From 1913 until his death on November 21, 1944, he resided in Cambridge, though meetings of the International Astronomical Union and the British Association, or special lectures and visits took him across three continents.

Eddington has been the prime interpreter of relativity theory in the English language. His powerful mathematical ability and insight made it possible for him to grasp the significance of Einstein's work against the background of Minkowski and the pioneers. DeSitter, Weyl, Eddington and later Lemaître, provided the early criticisms and developments of the theory. Eddington published a *Report on the Relativity Theory of Gravitation* and *Space Time and Gravitation* in 1920, followed soon after by *The Mathematical Theory of Relativity*, and in 1938 *Relativity Theory of Protons and Electrons*. He has consistently upheld the theory of an expanding universe since 1930 and from this cosmological basis combined with quantum theory he has developed his most daring work—the synthesis of a world structure relating all the fundamental physical constants. From three measured constants—the velocity of light and the Rydberg and Faraday constants for hydrogen—his theory enables him to calculate with no further dependence upon observation thirteen constants including the charge on an electron and its mass, the mass of a proton and a hydrogen atom; Planck's constant, gravitation constant; mass of the universe, number of particles in the universe and speed of recession of the spirals. The agreement of ten of these quantities with the values determined in laboratory or observatory is so remarkable that his theory deserves the closest scrutiny by those with the mathematical ability to do so critically. Max Born, like Herbert Dingle, dislikes the Aristotelianism of this work, and attributes its success to

Eddington's "personal genius and insight." These and other qualities enabled him to "spin the gossamers as well as forge the anchors of the mind" and who shall say what of his work future assessors will regard as his profoundest contributions?

The name of Eddington will always be associated in the minds of astronomers with some of the great peaks in the advance of this science in the last three decades: the first verification of the Einstein deflection of light from Eddington's eclipse photographs at Principe Island and Crommelin's at Sobral in May 1919; his recognition of the importance of radiation pressure as a prime factor in stellar stability; the theoretical calculation of stellar diameters and of the density of Sirius B; the Mass-Luminosity law; the central temperatures of stars; interstellar gases; the age of the universe. His books in these fields are *The Internal Constitution of the Stars* and the non-mathematical smaller books *Stars and Atoms* and *The Expanding Universe* and his Bakerian and Halley lectures.

Eddington's three books dealing with philosophy and physical science are already mentioned. Add to them his Swarthmore lecture *Science and the Unseen World*, and we have a body of literature, rightly so called, for it has great literary merit as well as being a source of penetrating honest thought and brilliant exposition. With rich metaphor and striking analogy, sometimes with subtle humour and sparkling wit, the symbolism of mathematics is translated into words as he unfolds the significance of relativity and quantum theories, wave mechanics, indeterminacy, theory of groups, probability, and speculations in cosmology.

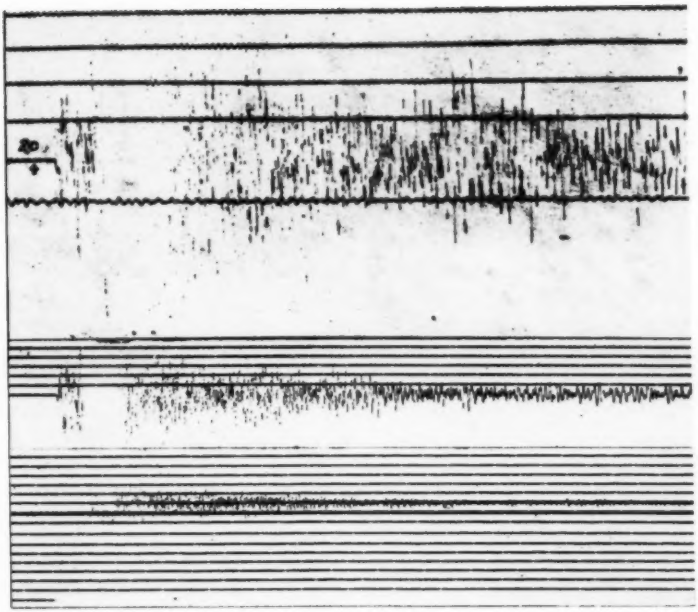
In compiling his philosophy, Eddington recognizes that the problem of experience has dual aspects—experience resulting in sense data in the realm of physical science which embraces all that is measurable, and a different but complimentary kind of experience which is an awareness of values and of the significance of things immeasurable and unseen save by the eye of the soul. No philosophy is complete which does not include both types of experience. His philosophy of science dealing with the symbolic world of physics is best described as Selective subjectivism and Structuralism, to use his own terms. But the same urge from within man's spirit which drives him to seek truth and evaluate experience in the

physical world, drives him with equally logical reasonableness to seek truth through spiritual apprehension, and to evaluate experience of beauty in nature, in art, in human personality, and in "the sense of a divine presence irradiating the soul." Faith, he insists, is fundamental to both approaches to the problem of experience. "In an age of reason, faith yet remains supreme, for reason is an article of faith."

The modern world owes much to the Society of Friends which has produced many men of great and good influence. This debt is immeasurably increased when we remember that Sir Arthur Eddington was of that company of devout seekers after truth. *Cum illo sint animae nostrae.*

Queen's University,
Kingston, Ontario,
1944, December **5.**

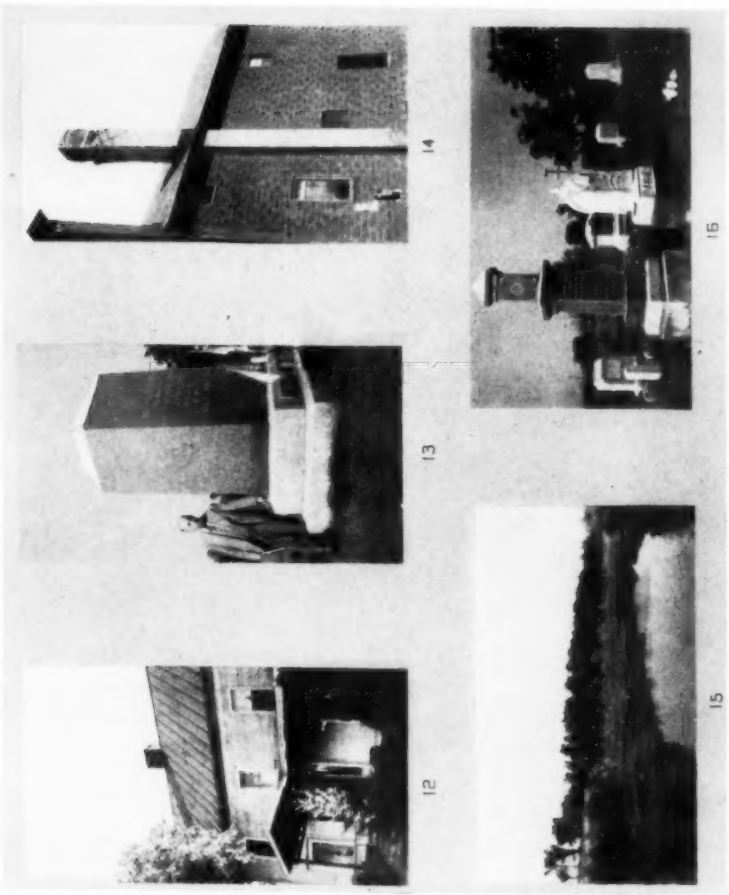
PLATE V



SEISMOGRAMS OF THREE MAJOR CANADIAN EARTHQUAKES

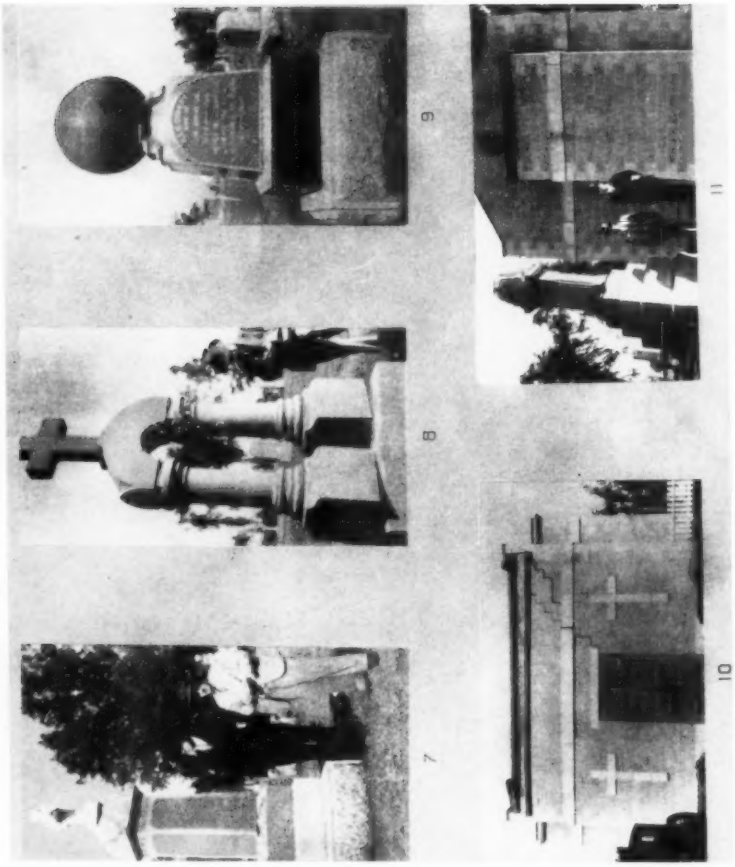
The illustration is a composite photographic reproduction of the seismograms of the earthquakes of 1925, 1935 and 1944, respectively having their epicentres in the lower St. Lawrence valley, at Timiskaming, Que., and at Cornwall. Each was made on the same Milne-Shaw seismograph at the Dominion Observatory, Ottawa. The 1925 quake was registered at a paper speed of 15 mm/min., the other two at 30 mm/min. In order that the relative duration of the preliminary phase might be on the same time scale on each record in the composite lay-out, the two lower seismograms were each reduced to half-scale. Hence, to compare recorded amplitudes, these two sections must each be multiplied by the factor 2. The epicentral distances were, respectively, 300 mi., 180 mi. and 60 mi. The ratio of focal energies may be determined by multiplying the recorded amplitudes by the squares of the respective epicentral distances. The ratio of focal energy release is thus, approximately, 26:12:1. That is to say, the St. Lawrence earthquake released about 26 times as much energy at the focus as did the Cornwall shock; and that at Timiskaming only about 12 times that much. Yet, the ratio of estimated damage was—5:1:200. This is largely due to the fact that the Cornwall epicentre was occupied by so many buildings, erected on a deep sandy terrain.

PLATE IV



The Cornwall-Massena Earthquake, September 5, 1944.

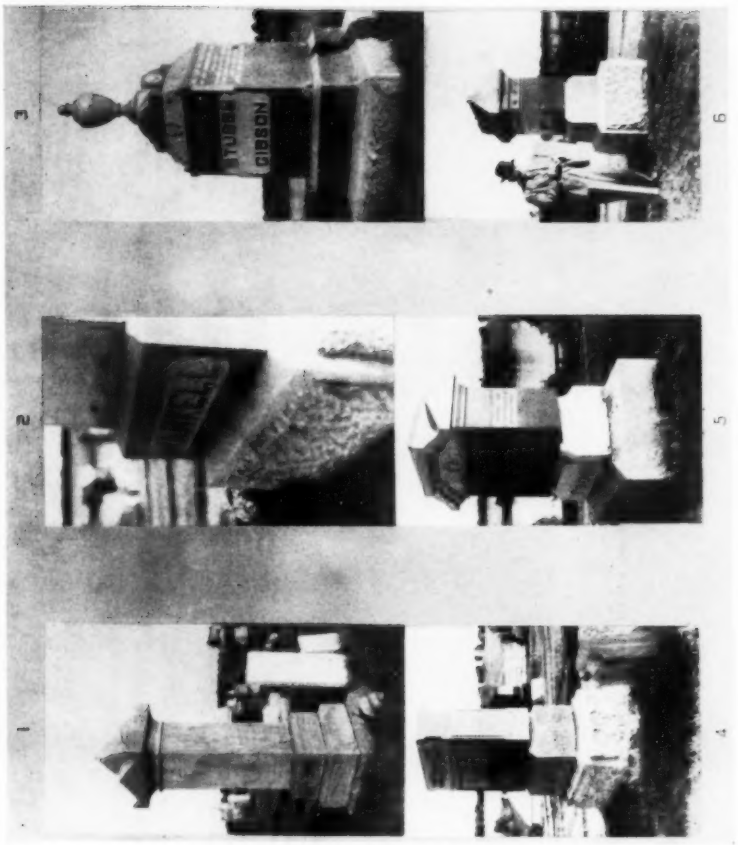
(Photograph by Lafayette, Ltd., supplied by courtesy of Harvard Observatory.)



The Cornwall-Massena Earthquake, September 5, 1944.

(Photograph by Lafayette, Ltd., supplied by courtesy of Harvard Observatory.)

PLATE II



The Cornwall-Massena Earthquake, September 5, 1944.

(Photograph by Lafayette, Ltd.,
supplied by courtesy of Harvard Observatory.)

THE CORNWALL-MASSENA EARTHQUAKE SEPTEMBER 5, 1944

By Ernest A. Hodgson

(With Plates II, III, IV, V)

SHORTLY before 12: 40, E.W.T., in the early morning of Tuesday September 5, 1944, a moderately severe earthquake disturbed many persons, some asleep, others up and about, over a widespread area in eastern Canada and New England. The papers next morning carried news items showing that it had been felt as far south as New York city, west to Windsor and Detroit, eastward to at least Quebec city, and up into the mining districts of northern Ontario and Quebec. Later reports indicated that it was felt at Rupert House on James Bay. The damage was confined to a comparatively small region in the vicinity of Cornwall, Ont., and Massena, N.Y., which lies about ten miles south-west of Cornwall. It recorded on seismographs at Pasadena, California.

The Ottawa seismographs recorded the tremors, but the disturbance was so great that it was difficult to determine the epicentral distance accurately from the first, main shock. However, there were quite a number of aftershocks felt in the vicinity of Cornwall and Massena, of which three were registered at Ottawa. The second of these, at about 5 a.m., E.W.T., September 5, was very well recorded. Determined from this record, the epicentral distance was found to be 59 miles. Using this value for distance, together with the time of the first onset of the initial disturbance, the computed focal time for the main earthquake was 4:38:44, U.T., September 5 (12:38:44, a.m. E.W.T., Sept. 5).

The seismogram from Shawinigan Falls was received at Ottawa within a couple of days. The main shock was here sufficiently attenuated by distance to permit a direct reading. Using the Shawinigan record alone, the focal time was independently determined as 12:38:42, E.W.T., and the distance from Shawinigan Falls to the epicentre was found to be 140 miles. The distance circles about Ottawa and about Shawinigan Falls intersect at a point a couple of miles south and a little east of the southern end of the international bridge at Cornwall.

It was decided that a field survey should be made from the Dominion Observatory. As the weather was fine and the epicentre evidently lay in a region of good roads, it was possible to use an automobile. Arrangements were made to have Mr. Hector Gauthier of the Observatory staff drive his own car and accompany the writer on the field trip. It was a most satisfactory arrangement —a great improvement over other earthquake field trips, made over rough country in bad weather and alone. It is surprising how much more can be accomplished with one to dictate observations and another to keep the notes. The car was not only a great convenience and comfort in getting from place to place, but it saved much time and permitted a greater coverage. The odometer readings conveniently located the place where each note was recorded.

Another fortunate circumstance was of very great assistance at the beginning of the investigation, when it was most needed. Just before leaving Ottawa, a visit was received at the Observatory from Mr. I. W. Clarke of the Montreal office of the Associated Factory Mutuals Insurance Company. He was returning from an inspection trip over the Cornwall-Massena area, carried out in company with Mr. H. A. Sweet from the Boston Head Office of the same organization. Mr. Clarke furnished some data of immediate value and arranged to have Mr. Sweet wait over at Cornwall in order to spend a day with the Ottawa men. From him much was learned about the distribution of damage in Cornwall and in Massena. He had not only visited the factories in which his company is interested but had interviewed civic engineers and others, inspected the general damage in various parts of Cornwall, collected photographs and news clippings and experienced some of the aftershocks.

One of the most helpful suggestions made by Mr. Sweet was that steps be taken to secure back copies of certain newspapers: the *Cornwall Standard Freeholder* (which had just issued a special extra containing exclusively their own earthquake news to Sept. 8), the *Massena Observer*, the *Watertown Times*, and the *Syracuse Post Standard*. The last named had published a questionnaire on the earthquake on behalf of Prof. G. Woodruff, of the Department of Geology, Colgate University, Hamilton, N.Y. This led to corre-

spondence with Prof. Woodruff, who has promised to place the data he collects at the disposal of the Observatory in the preparation of a later report on this earthquake. Mr. Sweet has furnished a copy of his inspection report, also to be consulted in preparing that publication.

Throughout the course of many contacts with newspaper men at the time of an earthquake, our experience has been that they are inclined to take all one can give them, after which they rewrite it into what is often a ridiculously exaggerated or inaccurate "story" and that they then invariably forget their promise to send a copy of that story as printed. It is particularly pleasant to report that, quite contrary to past experience and to then expectation, every newspaper consulted in this investigation not only placed all available information freely at our disposal and gave excellent and accurate reports of interviews, but in no case did they neglect to send a copy of what they had written. Some are continuing their collaboration by making studies of their back files. This is particularly true in the case of Editor Harold B. Johnson, of the *Watertown Daily Times*.

The trip of inspection was begun in the late afternoon of Saturday, September 9. Surveying was carried out en route from Morrisburg to Cornwall, where Mr. Sweet was found waiting. The group was at dinner in the Cornwallis Hotal at 7:25 that evening, when a severe aftershock was experienced, which brought all diners to their feet in a hurry. Fortunately, the tremors lasted only a few seconds; there was no time for panic. The disturbance began as a faint rumble, quickly becoming stronger and followed by an explosive *bang*, which felt as though the boiler had exploded in the basement, after which it terminated with a few rumbling sounds. It was decidedly the most severe shock which the writer has ever felt in his limited personal experience. It was registered at Ottawa, where the seismographs showed it to be of about the same intensity as the one at 5 a.m. on September 5. These two have been, so far, the most severe of the many aftershocks, which were at first experienced every few hours and than at increasingly longer intervals, continuing up to the date of writing this account.

In an interview with Mayor Horowitz, the writer discussed the damage in Cornwall. There are 3081 buildings in that municipality

proper. An estimate of an average of $200 damage to each of these was made, after a general survey, by a group of contractors and engineers. In addition, there was considerable damage to public buildings, factories, etc. The total rough estimates ran from $750,000 to $1,000,000. At the time of the interview, few of the more precise determinations of damage to particular buildings were yet available. About 2,000 chimneys alone were so badly damaged in Cornwall as to require repairs. Considerable loss was suffered by householders and storekeepers from the destruction of glassware, etc., and the cracking of brick and plaster walls. It is a nice question just what is meant by total earthquake damage.

If every house, public building and factory is to be put back into the same condition as before the earthquake, and if all rooms are to be re-decorated, all broken articles replaced, etc., then such an estimate of the damage rests at the maximum value. If the money which will actually be expended in recovering from the disaster is to be taken as the measure, the estimate will be a minimum. The difference between these two figures is evidently large. Cracked walls of churches, factories, etc., may be strengthened with bolts and plastered over. Some will be replaced. Much of the broken glassware in private houses will be written off. Many square yards of cracked plaster will remain cracked. After having seen samples of the damage in many parts of Cornwall, it would seem that the $1,000,000 estimate is close to the maximum referred to above.

But, whatever the estimate adopted, the damage was plenty; whether one considers it from the point of view of the private citizen forced to get his chimney repaired in a hurry, or that of the factory executive faced with the need for prompt attention to a 200-foot smokestack, or that of the school trustees required, literally at a moment's notice, to put the schools into condition to meet the insistent demands (?) of the school population just getting back after the holiday season.

Mayor Horowitz enquired as to the likelihood of further serious shocks. It was pleasant to be able to assure him, on the basis of all previous experience, personal and derived from reports on many earthquakes, that, while it was practically certain that there would be aftershocks varying in intensity but gradually becoming less

and occurring at longer intervals, it was not at all likely that any of the aftershocks would be more severe than the two large ones already experienced. This report was published in the *Cornwall Standard Freeholder* (a very accurate report of the statements made) and was said to have been of considerable comfort to many.

A warning was added that chimneys should be carefully checked, both above the walls and within them, and repaired at once if any cracks were found. This was a difficult prescription to have filled, as there was a marked scarcity of both bricks and bricklayers, due to wartime regulations governing both men and materials. However, the Mayor and his assistants did manage to secure the authority, the supplies and the men to meet the need, and the weather was most accommodating.

The damage in Massena was also estimated at $1,000,000. Here, too, there were said to be 2,000 chimneys requiring repairs. The chimney damage seemed about as great there as in Cornwall, but the sum total of all reports received during the investigation left one with the feeling that the overall damage in Massena was, perhaps, somewhat less than that in Cornwall. This would appear to have been due to differences in foundation subsoil, rather than to any difference in the severity of the tremors; for there was plenty of evidence that Massena is probably closer to the epicentre than is Cornwall. Some wells in the vicinity (and also across the river on the north shore) were said to have dried up, others began to flow, and a crack in deep alluvium north of Massena Centre oozed water and sand. Such phenomena are generally found in epicentral regions.

The investigation in Massena owes much to the collaboration of Mr. Leonard Prince of the Massena Observer, who not only furnished data on local conditions after the earthquake, but made it possible to meet executives of some of the local industries. In this way, within a few hours, a surprising amount of information was obtained and further data were promised. This material can receive only general attention here, but will be dealt with fully in a later report, as will similar data obtained from executives of companies in Cornwall, resulting from contacts made through the Kiwanis Club there. Such data cannot properly be published without a release from the organizations concerned.

One of the field evidences sought when on a trip of this kind is of a negative nature: old chimneys which were not damaged, old barns obviously rickety which did not collapse, etc. It was surprising to find that the negative evidence began to show up quite markedly only five miles or so east of Cornwall on the Canadian side, and within about the same distance eastward from the international bridge on the south side of the river. Almost none was found at Hogansburg and none at all in Ft. Covington. But the damage tapered off at a much slower rate going west. It was more than fifteen miles west of the Cornwall-Massena region before marked negative evidence was found, at Waddington on the south shore and Morrisburg on the north.

The damage was reported by Clarke and Sweet to be spotty and, as is always the case, this spotty damage marks the parts having deep or sandy subsoil. This fact is particularly noticeable in the city of Cornwall, where information as to subsoil conditions was furnished to Mr. Sweet by Col. W. H. Magwood, the City Engineer. Those parts of Cornwall which suffered the least damage were, definitely, the sections which are not underlain by a sandy deposit sometimes spoken of locally as "quicksand", although, technically, this is said to be a misnomer. More will appear presently in this connection when speaking of the damage in the Cornwall cemeteries.

In any field study in an epicentral region, the investigator makes it a point to visit the cemeteries. If it were known beforehand that an earthquake would occur in a given locality, much information could be obtained by setting up regular, symmetrical columns of various dimensions on solid, level bases and, after the earthquake, making a study of its effects on these columns. Where could one find a more effectively based, carefully placed set of "seismoscopes" of various dimensions than in a modern, well-kept cemetery?

Accordingly, care was taken to visit every cemetery which could be found to have suffered any damage. In all, careful surveys were made of fourteen in the epicentral region. As sufficient photographic film for only eighteen exposures could be obtained during the time of the field trip, most of the pictures were taken in the cemeteries and, consequently, nearly all the illus-

trations in this article show the earthquake effects on gravestones.

The first cemetery visited, and the one farthest from the epicentre to show marked damage, is at Farrans Point, Ont., on the St. Lawrence, twelve or thirteen miles (in an air line) west of Cornwall. The six illustrations of Plate II show effects in this cemetery. It is to be noted that the stones are, in general, modern and well-placed, and that the grounds are fairly level and well tended. It will be noticed that, in nearly every case, they have been turned on their bases, and that all rotations are in a contra-clockwise sense. Every stone in this cemetery which was rotated (and there were at least twenty) was so directed. The stone in Fig. 2 was shifted bodily west at the grass line, leaving a crack about two inches wide. Note that the urn (in Fig. 1) was found lying close to the plinth. Reference will be again made to this fact. The marks in the soft soil showed that it had fallen where it lay at the time the picture was taken.

In Cornwall, there are three cemeteries of the larger type: the "French" cemetery in the north-east corner of the town, St. Columban's in the north-west corner, and Woodlawn, half a mile or so directly south from St. Columban's. According to Col. Magwood, as reported by Mr. Sweet, the north-east corner of Cornwall was once an island in a much wider St. Lawrence river. Certain it is that the layer of "quicksand" is not found there. Chimney damage in this district was very much less than in any other part of Cornwall. The stones in the "French" cemetery, located in this part of town, were in good order, with three minor exceptions. The caretaker stated that no repairs had been made—there simply had not been any damage.

Less than two miles directly west of this cemetery is St. Columban's. Here there is a sandy subsoil. Hardly a stone in the large burying ground was left undamaged. Two of these are shown in Figs. 7 and 8. Another, shown in Fig. 11, is quite large, as is evident in comparison with Messrs. Gauthier and Sweet standing beside it. It was not leaning, as might be suspected. The camera was not held level. Figs. 10 and 11 show the vault at St. Columban's. It is of cement blocks and will have to be re-built. Most cement block structures, especially chimneys and garages, in the epicentral region were generally damaged as was this vault.

In Fig. 9 is shown a remarkable case of contra-clockwise rotation in Woodlawn cemetery. The granite ball is highly polished and is about two feet in diameter. Scratches on its surface show that the ball was rotated contra-clockwise by the amount by which the strip of paper extends to the right of the supporting claw. Each of the four claws gave the same measure of rotation indication.

All the stones which rotated in Farrans Point cemetery turned contra-clockwise. About 70 per cent of all rotated stones in cemeteries on the north shore rotated in this sense also. Exceptions to the rule were mostly in a closely related group in each case, usually close to trees.

On the south shore an even higher percentage of rotated monuments were turned in a clockwise sense. Examples are shown in Figs. 13 and 16. These pictures were taken in a cemetery at Massena Center, about four miles east of Massena. Nearly all the stones in this cemetery, and a very large percentage of those in a large cemetery in Massena, were damaged, most of them by being rotated. And, in most cases, the rotation sense was clockwise. Exceptions to this rule, in the Massena cemetery, were again almost entirely confined to isolated groups close to trees.

It is also to be noted that the urn, which has fallen from the smaller monument in Fig. 16, did not part at a joint. The neck of the ornament was broken. It was thrown clear, a good three feet from the base. Marks in the soil, and absence of scratches on the monument, testify to the fact that it did not roll to the point shown. Compare this fall with that in the Farrans Point cemetery, as shown in Fig. 1. In general, the direction of fall of ornaments in cemeteries and of other objects in different locations was so varied that little significance could be given this type of evidence. Just what significance attaches to the consistent partition of rotation direction north and south of the river the writer is not prepared to say.

One of the most convincing pieces of evidence, supporting the deduction that one is near the epicentre, is the prevalence of chimneys damaged as shown in Figs. 12 and 14. The earthquake blows are here delivered with such force and in so nearly vertical a direction that the bricks of the chimney have been jarred apart but have not fallen from the chimney. There were some "up-

bumped" chimneys in Cornwall; one of the best examples in Massena is shown in Fig. 14; but in Massena Center nearly every chimney in the village was so damaged, as was the one shown in Fig. 12. This fact, taken in conjunction with the great disturbance of the monuments in the cemetery there, indicate that the epicentre was very close to Massena Center. This is about five miles west of the intersection of the distance circles about Ottawa and Shawinigan Falls. The point of intersection is close to the scene shown in Fig. 15. Had there been a town at this particular spot, it might have been damaged even more than was Massena Center.

So, tentatively, the epicentre is thought to be somewhere in the vicinity of Massena Center, and the focal depth is probably fairly deep—20 miles or so, since the tremors of what was really not a major earthquake were felt to such great distances. Certainly the shock was less than that of the Timiskaming earthquake of November 1, 1935, and very much less than that which had its epicentre on the south shore of the St. Lawrence, about 40 miles below Quebec city, on February 28, 1925.

A complete study of the Cornwall-Massena earthquake is being undertaken by the Dominion Observatory. Seismograms from all seismograph stations in North America have been requested. A widely-distributed questionnaire has been sent out in Canada, in addition to those in the United States. Many co-operating agencies and organizations are furnishing data. When all have been studied, a report will be compiled which may change by small amounts the present, tentative deduction that the Cornwall-Massena earthquake occurred at the focal time 4:38:44, U.T., September 5, 1944, with the epicentre near Massena Center, N.Y., and the focal depth of the order of 20 miles.

Dominion Observatory,
Ottawa, Canada.
December 4, 1944.

JUPITER AND SATELLITES I, II, III AND IV DURING 1945

By Charles E. Apgar

THE following tables, in continuation of work published previous years in The Journal, gives the periods, during 1945, when Jupiter's satellites will be either all East or all West of Jupiter. The times given are for 75th meridian (Eastern Standard Time).

1945		All	Begins at		Duration	
Jan.	1.....	East	14h	14m	1h	37m
	7.....	East	2	47	13	53
	9.....	West	13	22	17	47
	21.....	East	7	40	*12	39
	22.....	East	19	41	3	27
	30.....	West	18	47	18	1.1
Feb.	4.....	East	12	25	11	28
	5.....	East	23	14	4	34
	14.....	West	0	51	15	43.7
	25.....	East	19	17	9	51
	28.....	West	7	31	12	50.8
Mar.	11.....	East	23	46	8	49
	13.....	East	7	56.3	7	08.7
	17.....	West	18	07	6	31
	21.....	West	17	22	8	29
	26.....	East	4	53.6	7	09.4
	27.....	East	11	44.6	7	49.4
Apr.	5.....	West	0	01	5	19
	7.....	West	23	21	11	10
	10.....	East	15	33.5	8	33.5
	16.....	East	12	38.5	4	41.5
	17.....	East	17	28.1	8	58.9
	19.....	West	6	51	2	02
	22.....	West	2	54	14	28
	26.....	West	10	22	0	18
May	1.....	East	21	17.8	9	54.2
	6.....	West	6	31	17	59
	14.....	East	22	57.5	1	37.5
	16.....	East	1	07.8	10	59.2
	27.....	West	12	05	18	54
	30.....	East	4	58.1	8	45.9
	30.....	East	15	38.2	1	31.8

1945		All	Begins at		Duration	
June	6.....	East	6	53.3	12	52.7
	10.....	West	15	53	18	55
	20.....	East	10	43.8	14	18.2
	24.....	West	19	44	18	56
July	1.....	West	21h	41m	15h	59m
	4.....	East	14	34.2	15	51.8
	16.....	West	1	30	18	59
	25.....	East	20	19.5	18	0.5
	30.....	West	6	53	17	41
Aug.	9.....	East	0	9.4	18	9.6
	13.....	West	16	25	12	10
	15.....	West	4	3	0	9
	20.....	West	15	19	15	17
	23.....	East	3	58.9	18	20.1
Oct.	19.....	East	4	32	9	54
	25.....	West	0	9	7	16
	29.....	East	10	31	9	58
Nov.	2.....	East	13	19	5	8
	5.....	East	12	31	10	53
	8.....	West	4	9	8	25.6
	14.....	West	6	6.1	2	58.3
	16.....	East	22	3	0	24
	19.....	East	16	30	17	12
	28.....	West	6	35	3	17.8
	29.....	West	10	7	10	12.5
Dec.	3.....	East	20	26	18	58
	12.....	West	11	59	1	40.1
	13.....	West	14	2	11	27.8
	18.....	East	0	38.7	18	41.3
	25.....	East	2	16	19	0
	26.....	West	17	17	0	8.1
	27.....	West	17	56	12	44.6

The following gives the eight periods during 1945 when Jupiter apparently will be attended by only one satellite.

Time given is that of longitude 75° West.

Configurations as observed through an inverting telescope.

Date 1945	Config'n	Begins at		Ends at		Duration	
June 15.....	d**-0-3	22h	5m	23h	13m	1h	8m
July 3.....	d**-0-4	13	56	15	44.4	1	48.4
10.....	*d*-0-4	16	50.8	18	8	1	17.2
14.....	4-0-d*d	4	53	5	29	0	36
17.....	4-0-**d	17	52	19	29	1	37
21.....	dd*-0-4†	6	51	9	5	2	14
24.....	**d-0-4	20	37	22	4	1	27
28.....	4-0-d*d	10	55	11	4	0	9

†Satellites II, III, I disappear within 15m.

Configurations:

0 represents the disc of the planet.

* signifies the satellite is occulted or eclipsed.

d signifies the satellite is on the disc.

549 Carleton Road,
Westfield, N.J.
Oct. 1, 1944.

JOVIAN CENTRAL MERIDIAN TRANSIT TIME ERRORS OF SATELLITES AND THEIR SHADOWS

By HUGH M. JOHNSON

THE method of obtaining longitudinal positions on the planets by simple visual estimation of transit times of identified marks across the central meridian is now well known. It was already a very old procedure when revived and put on a systematic footing for Jupiter by the late A. S. Williams several decades ago, and its pursuit now comprises the bulk of the work of such groups as the Jupiter Section of the British Astronomical Association. A new general investigation of the errors inherent in the method therefore seems proper, particularly as its reliability has been questioned in the past, granting its uncontested facility and availability to the ordinary amateur. B. M. Peek[1] has briefly noted the subject, stating with apparent generality that the expected error of a single visual estimate of a Jovian transit time is about 2 or 3 minutes but rarely greater than 5 minutes, though without giving the basis for his opinion and without specifying whether he considers these figures measures of combined accidental and systematic errors or of the former alone. Now, apparently the only general means employed in determining the magnitude and sign of these errors has been that of internal comparison of various transit observations. Accidental errors may be thus well determined and an observer's personal equation relative to those of other observers may be disclosed. But any systematic error to which all observers are subject in some degree will be undiscovered. We need, then, an independent method of transit timing incurring all these errors and distinctly measurable for each. In 1939 I realized the problem and came upon a likely solution in the similarities of transits of the satellites and their shadows across the central meridian, the times of which may be predicted. Indeed, such satellite phenomena are so commonplace that it will be strange if they have not been so thought of before.

In the following treatment we shall establish prediction formulæ on the basis of ingress time t_i and egress time t_e of satellite or shadow

[1] *The Observatory*, vol. 59, p. 272, 1936; *J.B.A.A.*, vol. 47, p. 153, 1937.

on the visible illuminated face of the planet, the data for which are readily available in the *American Ephemeris and Nautical Almanac*. It has been suggested to me that a simpler treatment could be derived for certain data in the *Connaissance des Temps*, but this publication has not been circulated in recent years. For the following we make the initial simplifying assumption that rays of light emanating at the earth or sun are parallel at Jupiter. We next assume that during the interval $t_e - t_i$ the satellite in question travels on a straight line at a uniform rate of motion. For this assumption it may be shown that the maximum difference between the actual position of the satellite projected normally from the orbital arc to its chord and the position on the chord from the assumption is an error of time no greater than in the second decimal place expressed in minutes. It may also be shown that the maximum difference between the actual position of a shadow on the surface of the planet and the central meridian position from the assumption is an error of similar magnitude. So that separately or combined these errors may be neglected. Our third assumption is that the satellite orbits shall be considered in the Jovian equatorial plane. Now if R is the satellite orbit radius and $D\oplus$, $D\odot$, respectively, are the zenocentric declinations of the earth and sun, to be chosen when dealing with satellite or shadow, respectively, $R \sin D$ is the apparent distance from the centre of the planet when the satellite falls at once on its orbital node and near the central meridian. It is at this time that the error resulting from the third assumption is at maximum and may be expressed as $R \sin D \sin (C + A - B)$, where the maximum value of D (about 3°.4) is to be used, except for satellite IV when $R \sin D$ then exceeds the Jovian polar radius which we must substitute for $R \sin D$ in such event, and where C is the inclination of the equator to the Jovian orbit, A is the inclination of the satellite orbit to the reference plane upon which its node regresses, and B is the inclination of the reference plane to the Jovian orbit. This is because said reference plane and Jovian orbit and equator have a common intersection, whence it is clear that the maximum inclination of a satellite orbit to the equator is

$C + A - B$. Table I lists the numerical values of A and B while $C = 3°.115$[2].

TABLE I

Orbit	A	B
I	0°.027	3°.112
II	0 .468	3 .097
III	0 .184	3 .038
IV	0 .254	2 .712

Employing the proper constants for each orbit we find the following numerical errors resulting from assumption three:

I—$0^m.0$, II—$0^m.4$, III—$0^m.4$, IV—$1^m.6$.

The *American Ephemeris* ingress and egress times used herein are based on H. Andoyer's[3] simplifications of R. A. Sampson's[4] *Tables of the Four Great Satellites of Jupiter* and are said to be correct to the nearest minute.[5] While the error just derived for satellite IV therefore exceeds that suffered from the prediction data as well as the possible minimum error of observation, we shall consider the third assumption tenable.

We may now frame the predicted time of central meridian transit for a *satellite* as simply

$$t_c = (t_e - t_i)/2. \qquad (1)$$

An inspection of the predicted time of central meridian transit for a *shadow* reveals that it is an important function of i, the angle between the earth and sun at Jupiter, or

[2]According to the United States Naval Observatory per W. J. Eckert in a letter.

[3]*Bulletin Astronomique*, vol. 32, p. 177, 1915.

[4]London, 1910.

[5]According to the United States Naval Observatory per W. J. Eckert in a letter. However, on 1944 April 19 W. H. Haas was sure that the shadow of III was entirely within the apparent outline of the planet at 1^h20^m U.T., the *American Ephemeris* published ingress time. On May 19 he observed the egress of the shadow of IV, finding internal contact at 0^h42^m and external contact at $0^h52^m.5$, while the published egress time is 0^h56^m. On May 21 he observed the ingress of the shadow of I, noting external contact by $0^h12^m.7$ and internal contact at $0^h14^m.4$, for which the published time is 0^h14^m. The gross discrepancies in two out of these three cases call for further test of the *American Ephemeris* predictions which, if generally as inaccurate as here indicated, may not be employed as in this paper.

$$t_e = t_i + (t_e - t_i)[1 \pm (2 \sin i - \sin^2 i)/(1 + \cos i)]/2 \quad (2)$$

where the sign of the term in i is positive preceding and negative following opposition. This formula implicitly assumes that the relative positions of the earth, sun and Jupiter are such that the position angle of the phase cusps is the same as the position angle of the polar axis, which is generally not true. The assumption is fulfilled approximately enough, however, except when i is quite small, and so will be held in some following developments.

I have had valuable co-operation in obtaining observational material for this paper from the following amateurs: D. P. Barcroft, C. M. Cyrus, F. L. Frazine, W. H. Haas, E. Reese, F. R. Vaughn, jr., and E. K. White; who observed at the following stations: (1) Madera, California, (2) St. Petersburg, Florida, (3) Des Moines, Iowa, (4) Rochester, New York, (5) New Waterford, Ohio, (6) Springfield, Pennsylvania, (7) Upper Darby, Pennsylvania, (8) Uniontown, Pennsylvania, (9) Lynchburg, Virginia, and (10) Ymir, B.C., Canada. Table II chronologically lists the observations over five apparitions in columns of which the first is the identifying number, the second the observer and station numbered as above, the third his telescope and magnification, the fourth seeing on a scale of 0 (poorest) to 10 (best), the fifth and sixth the observed date and time of transit t_o, the seventh the observed satellite (asterisked) or shadow. Columns eight, nine and ten continue with the value of i, t_i and t_e from the *American Ephemeris* and column eleven t_c from (1) or (2). Column twelve gives the difference $t_c - t_o$. If we regard a transit error as the longitudinal angle σ a marking departs from the central meridian before the eye notices the departure, we may define this angle by the expression

$$\sin \sigma = 2(\sec i)(t_c - t_o)/T,$$

where T is the duration of time a satellite occupies an orbital arc the chord of which equals the chord of the apparent outline of the planet tangent to the apparent path of the satellite or shadow at the central meridian, and where sec i is a factor used in the case of a shadow only. As the numerical value of sec i never exceeds 1.022, however, we shall neglect it. Now

$$(t_e - t_i)/T = [(R^2 - \chi^2)/(R^2 - 1)]^{\frac{1}{2}}$$

in which χ is the ratio between the chord joining ingress and egress points and the equatorial chord, when R is in terms of Jovian equatorial radii. As χ approaches zero the right hand member of the equation approaches $R/(R^2 - 1)^{\frac{1}{2}}$ as a limit. The largest numerical value which this limit may attain, of course for satellite I here, is less than 1.015, so that it is proper to substitute $t_e - t_i$ for T yielding finally

$$\sin \sigma = 2(t_c - t_o)/(t_e - t_i). \qquad (3)$$

Column thirteen, then, gives σ from (3).

In addition to these notes, Haas recorded transparency of sky on a scale of 0 to 5 for a number of his observations, but these records are omitted. We have before us now 91 data which if homogeneous would be an adequate number for inquiry in combination. The actual lack of homogeneity, which, however, is no greater than that usually encountered in a group series of transit observations of surface features for the determination of longitudinal drifts, may derive from two classes of source: first, variations in the conditions of the observing, and second, variations in the conditions of the observed objects. The first class includes the idiosyncracies of the observer, which he cannot escape, qualities of climate such as seeing, which he cannot control, and qualities of instrument such as aperture and magnification, which he may often select; all of which affect the apparent condition of the observed object. The second class comprises such qualities as size of satellite or shadow and contrast with the surface against which it is seen, the configuration of surrounding surface marks, latitudinal position of transit, and the phase darkening and dulling of the terminator side of the planet compared with the bright, sharp limb side, suspected[6] of causing a systematic error in transit timing of opposite signs before and after opposition in the same sense as though the phase were exaggerated over its geometrical extent. The data may be manipulated so as to evade some of these sources of discord, or so as to isolate some of them, usually most simply by selecting particular data which, however, runs the risk of reducing their number too far with such a limited set to begin with. Here I shall only attempt three approaches to the 91

[6] *Memoirs of the B.A.A.*, vol. 14, part 3, p. 87, 1906.

TABLE II

No.	Obs.	Telescope	Seeing	Date	t_0	Obj.	i	t_I	t_E	t_C	$t_C - t_O$	ϵ
					h m		°	h m	h m	h m	m	°
1	FLF (2)	12 in. rl. 250×	1938	Aug. 13	2 30	I	1.8	1 21	3 39	2 32	+2	+2
2	FLF (2)	12 in. rl. 250×		Sept. 2	1 14	II	2.6	23 56†	2 47	1 18	+4	+3
3	FLF (2)	12 in. rl. 250×		Sept. 21	0 50	I	6.4	23 53†	2 11	0 55	+5	+4
4	WHH (3)	6 in. rl. 112×	3–4 1939	July 6	9 57	III	11.8	8 20	11 17	10 05	+8	+5
5	WHH (3)	6 in. rl. 112×	5	Aug. 18	9 59	III	8.1	8 24	11 16	10 01	+2	+1
6	HMJ (3)	12 in. rl. 190×	1940	July 3	9 27	I	10.4	8 16	10 25	9 31	+4	+4
7	HMJ (3)	8 in. rl. 213×		July 8	9 02	II	10.7	7 44	10 17	9 13	+11	+8
8	WHH (5)	6 in. rl. 192×		Aug. 18	9 41	I	11.6	8 35	10 44	9 51	+10	+9
9	HMJ (3)	8 in. rl. 213×	6	Aug. 27	6 07	I	11.2	4 57	7 06	6 13	+6	+5
10	WHH (5)	6 in. rl. 192×	5	Sept. 1	7 09	III	10.8	6 10	8 08	7 19	+10	+10
11	HMJ (3)	8 in. rl. 213×	8–9	Sept. 1	7 11	III	10.8	6 10	8 08	7 19	+8	+8
12	WHH (5)	6 in. rl. 192×	5	Sept. 3	6 08	II	10.6	4 39	7 12	6 08	0	0
13	WHH (5)	6 in. rl. 192×	6	Sept. 3	7 58	I	10.6	6 51	8 59	8 06	+8	+7
14	WHH (5)	6 in. rl. 240×	5–6	Sept. 19	6 13	I	8.8	5 06	7 15	6 20	+7	+6
15	HMJ (3)	8 in. rl. 213×	3	Oct. 5	4 29	I	6.2	3 22	5 32	4 34	+5	+4
16	HMJ (3)	8 in. rl. 213×	3	Oct. 5	5 48	II	6.2	4 28	7 02	5 53	+5	+4
17	FRV (3)	8 in. rl. 300×		Oct. 5	5 53	II	6.2	4 28	7 02	5 53	0	0
18	FRV (3)	8 in. rl. 300×		Oct. 12	6 22	I	4.9	5 16	7 26	6 26	+4	+4
19	DPB (1)	6 in. rl. 144×		Oct. 28	4 31	I	1.4	3.33	5.43	4.40	+9	+8
20	DPB (1)	6 in. rl. 144×		Nov. 4	6 23	I	0.2	5 28	7 37	6 32	+9	+8
21	DPB (1)	6 in. rl. 144×		Nov. 6	5 27	II	0.7	4 18	6 52	5 34	+7	+5
22	HMJ (3)	8 in. rl. 213×		Nov. 13	2 38	I*	2.2	1 36	3 44	2 40	+2	+2
23	HMJ (3)	8 in. rl. 213×		Nov. 13	2 51	I	2.2	1 51	4 00	2 53	+2	+2
24	HMJ (3)	8 in. rr. 240×	6	Nov. 19	3 16	III	3.5	2 18	4 13	3 12	−4	−4
25	FRV (3)	8 in. rl. 300×		Dec. 1	2 38	II	6.2	1 31	4 04	2 42	+4	+3
26	DPB (1)	6 in. rl. 144×	1941	Jan. 1	3 15	III	10.3	2 28	4 23	3 16	+1	+1
27	FRV (3)	8 in. rl. 300×	7	Feb. 5	23 20	III	11.3	22 39	0 34‡	23 26	+6	+6
28	FRV (3)	8 in. rl. 300×	7	Feb. 6	1 47	I	11.3	0 56	3 05	1 49	+2	+2
29	HMJ (3)	8 in. rl. 213×	7	Feb. 6	1 51	I	11.3	0 56	3 05	1 49	−2	−2
30	DPB (1)	6 in. rl. 96×		Feb. 13	3 25	III	11.0	2 41	4 36	3 28	+3	+3

ABBREVIATIONS: rl., reflector; rr., refractor;
*Satellite itself. †Of preceding day. ‡Of following day.
a Shadow sharp and black, seen very clearly.
b Shadow was seen only with much difficulty.
c Observed value poor because of the extreme paleness of Jupiter on the bright sky.
d Satellite not seen well. *e* Observed value poor. *f* Shadow seen easily.

TABLE II—Continued

No.	Obs.	Telescope	Seeing	Date	to	Obj.	i	ti	te	tc	tc − to	σ
					h m		°	h m	h m	h m	m	°
31	WHH (5)	6 in. rl. 192×	4–7	Aug. 3	8 39	II	9.6	7 12	9 47	8 41	+2	+1
32	WHH (5)	6 in. rl. 192×	4	Aug. 23	7 52	I	11.0	6 37	8 47	7 53	+1	+1
33	WHH (5)	6 in. rl. 96×	2–3	Aug. 28	5 46	II	11.2	4 16	6 52	5 48	+2	+1
34	WHH (5)	6 in. rl. 96×, 192×	3	Aug. 30	9 44	I	11.3	8 31	10 40	9 47	+3	+3
35	HMJ (4)	5 in. rl. 192×	6	Oct. 15	10 02	I	9.8	8 49	10 59	10 04	+2	+2
36	FRV (4)	5 in. rl. 192×	5–6	Oct. 15	10 04	I	9.8	8 49	10 59	10 04	0	0
37	ER (8)	6 in. rl. 240×		Oct. 17	5 25	I*	9.6	4 24	6 34	5 29	+4	+4
38	WHH (7)	18 in. rr. 150×	4‡6	Oct. 24	6 22	Ia	8.8	5 10	7 21	6 25	+3	+3
39	HMJ (4)	7 in. rl. 177×	7	Nov. 5	8 15	III	6.9	6 53	9 20	8 15	0	0
40	FRV (4)	7 in. rl. 177×		Nov. 5	8 15	III	6.9	6 53	9 20	8 15	0	0
41	FRV (4)	7 in. rl. 295×	3–6	Nov. 7	10 09	I	6.6	8 58	11 08	10 10	+1	+1
42	HMJ (4)	7 in. rl. 295×	6	Nov. 7	10 12	I	6.6	8 58	11 08	10 10	−2	+2
43	CMC (9)	10 in. rl. 250×	1–2	Nov. 9	4 36	I	6.2	3 26	5 37	4 38	+2	+2
44	FRV (4)	7 in. rl.	5–6	Nov. 14	10 20	II	5.3	8 55	11 35	10 22	+2	+1
45	WHH (7)	18 in. rr. 300×	5–6	Nov. 16	6 26	I	4.9	5 20	7 31	6 31	+5	+4
46	FRV (7)	18 in. rr. 300×	6	Nov. 16	6 27	I	4.9	5 20	7 31	6 31	+4	+4
47	HMJ (7)	18 in. rr. 300×	7	Nov. 16	6 30	I	4.9	5 20	7 31	6 31	+1	+1
48	WHH (7)	18 in. rr. 300×	5	Nov. 16	6 55	I*	4.9	5 54	8 04	6 59	+4	+4
49	HMJ (7)	18 in. rr. 300×	6	Nov. 16	6 58	I*	4.9	5 54	8 04	6 59	+1	+1
50	CMC (9)	10 in. rl. 250×	2–3	Nov. 25	2 45	I	3.1	1 42	3 53	2 51	+6	+5
51	CMC (9)	10 in. rl.		Dec. 2	4 41	I	1.5	3 36	5 47	4 43	+2	+2
52	CMC (9)	10 in. rl.		Dec. 2	4 53	II	1.5	3 29	6 10	4 52	−1	−1
53	WHH (7)	18 in. rr. 150×	3–6	Dec. 9	6 33	I	0.2	5 30	7 42	6 36	+3	+3
54	CMC (9)	10 in. rl.		Dec. 11	1 02	I	0.5	23 59†	2 10	1 04	+2	+2
55	WHH (7)	18 in. rr. 150×	3–4	Dec. 16	8 25	I	1.3	7 24	9 36	8 28	+3	+3
56	HMJ (4)	5 in. rl. 192×	6	Dec. 18	8 02	III	2.0	6 49	9 24	8 04	+2	+1
57	CMC (9)	10 in. rl. 270×	7	Dec. 27	1 56	II	3.9	0 41	3 22	1 56	0	0
58	WHH (7)	18 in. rr. 300×	5	1942 Feb. 2	3 14	I	9.7	2 19	4 31	3 15	+1	+1
59	WHH (7)	18 in. rr. 150×	0–2	Feb. 9	5 09	I	10.4	4 14	6 26	5 09	0	0
60	WHH (7)	18 in. rr. 227×	1–2	Mar. 7	3 57	III	11.2	2 54	5 40	4 02	+5	+3
61	WHH (7)	18 in. rr. 200×	2–3	Mar. 8	4 05	II	11.2	3 00	5 41	4 06	+1	+1
62	WHH (7)	18 in. rr. 200×	4	Mar. 25	22 35	II	10.6	21 33	0 14‡	22 40	+5	+4

TABLE II—Continued

No.	Obs.	Telescope	Seeing	Date	t_o	Obj.	i_i	t_i	t_e	t_c	$t_c - t_o$	σ
					h m			h m	h m	h m	m	°
63	WHH (7)	18 in. rr. 300×	4–6	Apr. 2	1 14	II	10.2	0 10	2 51	1 17	+3	+2
64	WHH (6)	5 in. rl. 125×	2–4	Apr. 5	2 00	II*b*	9.9	1 08	3 21	2 04	+4	+3
65	EKW (10)	9 in. rl. 170×	1–2	Apr. 9	4 00	II	9.6	2 46	5 28	3 55	−5	−4
66	WHH (7)	18 in. rr. 200× 300×	5–7	Apr. 12	0 07	III	9.4	22 57†	1 48	0 09	+2	+1
67	WHH (7)	18 in. rr. 200×	4–5	Apr. 13	22 27	I	9.2	21 33	23 45	22 29	+2	+2
68	EKW (10)	9 in. rl. 170×	2–3	Apr. 19	3 58	III	8.7	2 58	5 50	4 12	+14	+9
69	WHH (7)	18 in. rr. 200×	5	Apr. 26	22 26	II*c*	7.9	21 16	23 59	22 27	+1	+1
70	WHH (7)	18 in. rr. 150×	0–2	Apr. 28	1 27	I**d*	7.8	0 29	2 42	1 36	+9	+8
71	WHH (7)	18 in. rr. 300×	3	May 14	0 07	I**d*	5.9	23 01†	1 15	0 08	+1	+1
72	WHH (7)	18 in. rr. 200× 300×	3	May 14	0 39	I	5.9	23 43†	1 56	0 43	+4	+3
73	WHH (7)	18 in. rr. 200× 300×	1–2	May 25	0 18	III	4.5	22 59†	1 58	0 22	+4	+3
74	WHH (5)	6 in. rl. 188×	4–5	Sept. 2	8 43	III	8.7	6 53	10 04	8 43	0	0
75	WHH (5)	6 in. rl. 94× 188×	4	Sept. 5	10 35	II*e*	9.0	8 55	11 40	10 29	−6	−4
76	WHH (7)	18 in. rr. 150×	5	Sept. 11	9 26	I	9.5	8 11	10 26	9 29	+3	+3
77	WHH (7)	18 in. rr. 300×	4–5	Sept. 11	10 26	I*	9.5	9 18	11 33	10 26	0	0
78	WHH (7)	18 in. rr. 300×	3–5	Sept. 24	9 28	IV*	10.4	8 09	11 08	9 39	+11	+7
79	WHH (7)	18 in. rr. 300×	3–4	Oct. 4	9 37	I	10.9	8 21	10 36	9 40	+3	+3
80	WHH (7)	18 in. rr. 300×	3–4	Oct. 4	10 42	I*	10.9	9 37	11 52	10 45	+3	+3
81	WHH (7)	18 in. rr. 300×	4–5	Oct. 8	9 26	III**e*	11.0	7 56	11 19	9 38	+12	+7
82	WHH (7)	18 in. rr. 300×	3–4	1943 Mar. 2	2 59	II*e*	8.9	1 52	4 43	3 05	+6/	+4
83	WHH (7)	18 in. rr. 300×	4–7	Mar. 9	2 05	I*	9.7	1 00	3 15	2 08	+3	+3
84	WHH (7)	18 in. rr. 300×	5–7	Mar. 9	2 59	I	9.7	2 06	4 22	3 03	+4	+3
85	WHH (7)	18 in. rr. 300×	3–4	Mar. 25	1 14	I	10.7	0 25	2 40	1 21	+7	+6
86	WHH (7)	18 in. rr. 300×	4	Mar. 29	3 38	III	10.9	2 20	5 51	3 47	+9	+5
87	WHH (7)	18 in. rr. 300×	4	Apr. 9	23 31	I	11.0	22 44	0 59‡	23 40	+9	+8
88	WHH (7)	18 in. rr. 200×	2–3	Apr. 24	2 20	I*	10.6	1 20	3 35	2 28	+8	+7
89	WHH (7)	18 in. rr. 200×	2–3	Apr. 24	3 24	I	10.6	2 34	4 49	3 30	+6	+5
90	WHH (7)	18 in. rr. 300×	0–2	May 3	23 37	III*f*	10.2	22 19	1 52‡	23 48	+11	+6
91	WHH (7)	18 in. rr. 300×	2–3	June 2	1 14	I*	7.6	0 13	2 29	1 21	+7	+6

observations, in general taking the errors in σ as distinct functions first, of seeing (70 observations), second, of latitudinal position, and third, of the hypothetical phase-exaggeration. This will be accomplished by deriving a least squares line for each case, the function then representing a measure of the systematic error and the root-mean-square s of the deviations from the line being taken as a measure of accidental error. As we come upon no *a priori* reasons for thinking any of the functions not linear, they will all be expressed in the form $y = ax + b$ with the errors as ordinates. A product-moment coefficient of correlation of the simple form

$$r = \Sigma(x - \bar{x})(y - \bar{y})/[\Sigma(x - \bar{x})^2 \cdot \Sigma(y - \bar{y})^2]^{\frac{1}{2}}$$

will then be given for the correlation of the errors with the argument, which may be taken as a correlation r_1 between systematic error and argument, and of the absolute deviations from the least squares line, which may be taken as a correlation r_2 between accidental error and argument. All the observations will be allowed equal weight for these computations.

In the first case of errors as a function of seeing, the seeing is assigned a mean value when recorded by more than one unit of the scale, the following numerical results emerging:

$a_1 = -0°.38$, $b_1 = +4°.5$, $s_1 = \pm 2°.9$, $r_{1.1} = -0.16$, $r_{1.2} = +0.03$.

If the errors and least squares line deviations increase with worse seeing, a_1, $r_{1.1}$ and $r_{1.2}$ must be negative. This occurs with a_1 and $r_{1.1}$ but the opposite is implied with $r_{1.2}$. Both latter absolute values are too small, however, to show any sensible correlation.

In the second case of errors as a function of latitudinal position, we may define this argument by the ratio $(t_e - t_i)/T_o$ in which T_o is the duration of time a satellite occupies an orbital arc the chord of which equals the Jovian equatorial diameter. A factor for phase, $2/(1 + \cos i)$, having a maximum numerical value of 1.011, may be neglected. Table III lists the numerical values of T_o for each satellite:

TABLE III

Satellite	T_o
I	138m
II	174
III	218
IV	292

The numerical values for the five results are:

$a_2 = -6°.84, b_2 = +9°.2, s_2 = \pm 2°.9, r_{2\cdot1} = -0.03, r_{2\cdot2} = -0.18.$

If the errors and least squares line deviations increase with greater latitude, a_2, $r_{2\cdot1}$ and $r_{2\cdot2}$ must be negative. This occurs here, but the absolute values of the coefficients of correlation are too small to demonstrate appreciable correlation. However, the mass of the observations are naturally near-equatorial transits and we have no near-polar transits, which might turn out to give a considerably different idea of the errors there.[7]

In the third case of errors as a function of phase-exaggeration, the function will be linear under the assumption that the effective phase like the geometrical phase varies as vers i, which is used as the argument, positive before opposition and negative following that date. We obtain

$a_3 = +11°.76, b_3 = +3°.0, s_3 = \pm 2°.9, r_{3\cdot1} = +0.04, r_{3\cdot2} = +0.03.$

If the errors and least squares line deviations indeed increase with increasing positive vers i, a_3, $r_{3\cdot1}$ and $r_{3\cdot2}$ must be positive, but again the absolute values of the coefficients of correlation are too small to indicate a correlation.

It cannot be said confidently that an inspection of Table II reveals larger or more variable errors among the infrequent observation contributors than among more active and experienced contributors. Nor does the work of Haas, who observed the most transits over the longest period of time, seem to show any progressive improvement in quality. Below is a table giving, for each apparition, the number of transits of Jovian surface markings recorded by Haas, the number of his satellite and shadow transits, their mean error, and the root-mean-square of deviations from the mean. Is there a relation between $\bar{\sigma}$ and s?

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[7]It might be suspected that the ratio of distances from the observed position of central meridian transit to the opposing limbs of the planet, equal to $1 \pm \sin \sigma$, should be roughly constant independently of latitudinal position. This might be an analogy with the Weber-Fechner law in psychophysics where the two distances concerned would be geometrical representations of stimuli, the fraction of the difference limen being then equal to sin σ.

TABLE IV

(Haas)

Apparition	Surface Tr.	Sat./Sh. Tr.	$\bar{\sigma}$	s
1936	1			
1937	27			
1938	98			
1939	457	2	$+3°$	$\pm 2°$
1940-41	618	5	$+6.4$	± 3.5
1941-42	305	23	$+2.4$	± 1.7
1942-43	673	18	$+4.0$	± 3.0

It may finally be asked whether these satellite or shadow transit errors are actually comparable with those of true surface markings, and, if so, what they indicate about them. How far the errors of the former may be taken for those of the latter must depend on comparability of motion and physical appearance. The eye infers motion for satellites and planetary detail alike from difference in position at distinct times, escaping the confusing of inequalities in appearance of *moving*, which is that case of greater motion for the eye where the difference of position occurs at indistinct times or seems continuous. The direction of motion for each is sensibly the same. In *size* satellites and shadows chance between the largest and smallest natural spots and are comparable with most in the range. In *shape* satellites and shadows, being round, are only approximated by many surface marks and not at all by the unbounded variety of others, some of which may be judged for "centre of gravity" and some of which may not. Of the latter no idea may be gained from our study for such cases as transits of preceding and following ends of longitudinally extended objects. In *contrast* shadows will always exceed that of almost any true mark and will therefore be much more easily seen, but at least certain of the satellites themselves usually match the subtlest variation in the surface, thereby being most difficult to observe in transit, and affording a differentiating test of error in relation to conspicuousness. The infrequency of appearance of satellite data in Table II does not yet permit this test to be made satisfactorily. And I find no definite answers to the introductory queries of this paragraph and so conclude fitly with a request for more satellite and shadow transit observations. The value of future work would be considerably enhanced over our past efforts if the observer will

be careful to note any peculiarities of the transit, such as situation with respect to surrounding markings, in addition to giving a personal estimate of the conspicuousness of the satellite or shadow, or of the difficulty of observing it. It is fortunate that these observations may be carried out concurrently with ordinary transit work with almost no additional effort.

I wish to thank all those who contributed observations making this article possible, and Messrs. Haas and Peek especially for ideas useful in the development of the subject.

126 Albemarle Street, Rochester, New York.
May, 1944.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

The Length of the Year

The following note arose from inquiries over the telephone which revealed that considerable confusion prevails in the use of the term *year*. Perhaps the writer may be pardoned for an attempt to elucidate the matter here.

The two chief units of time are the *day* and the *year*. The former is the rotation-period of the earth on its axis; the latter, its revolution-period round the sun.

At the instant when the centre of the sun is on the meridian we say it is solar noon, and the interval between two successive such noons is a solar day. The lengths of such intervals are not all equal, and their average length is a *mean solar day*. This is the day in common use; it contains 86,400 seconds as ticked off by your watch.

How shall we determine the length of the year? While we are persuaded that the earth revolves about the sun, to us the sun appears to move, in the course of the year, about the sky in a circle which we call the ecliptic, and which intersects the celestial equator in two points. When the sun is at that one of these points as it is moving from the south side to the north side of the celestial equator, it is the spring equinox (March 21); when at the other, it is the autumn equinox (September 23). The interval from one spring equinox to the next one is a *tropical year*, or a year of the seasons. By it our lives are governed. Such years vary in length considerably, and their average length is 365d. 5h. 48m. 46s. (approximately).

It may be interesting to give the actual length of some of these tropical years. In the Observer's Handbook is stated each year the date of the spring equinox, correct to one minute, and by writing down these dates for a series of years one can calculate the length of the tropical year elapsing from one equinox to the next. In this way the following table was prepared for the years 1928-45.

Year	Equinox				Length of Year		
		d	h	m	d	h	m
1928.....	Mar.	20	15	45	...	.	..
1929.....	"	20	21	35	365	5	50
1930.....	"	21	3	30	"	5	55
1931.....	"	21	9	7	"	5	37
1932.....	"	20	14	54	"	5	47
1933.....	"	20	20	43	"	5	49
1934.....	"	21	2	28	"	5	45
1935.....	"	21	8	18	"	5	50
1936.....	"	20	13	58	"	5	40
1937.....	"	20	19	45	"	5	47
1938.....	"	21	1	43	"	5	58
1939.....	"	21	7	29	"	5	46
1940.....	"	20	13	24	"	5	55
1941.....	"	20	19	21	"	5	57
1942.....	"	21	1	11	"	5	50
1943.....	"	21	7	3	"	5	52
1944.....	"	20	12	49	"	5	46
1945.....	"	20	18	38	"	5	49

It will be seen that the year 1931 was 17m. shorter than the year 1938.

The cause of this variation lies partly in the attraction of the other planets, particularly the massive Jupiter and Saturn, upon the earth, helping it forward at some parts of its orbit and holding it back at others.

The remainder of the variation is due to changes in the position of the equinoxes themselves; this is known as notation, and is produced by varying lunar attractions. C. A. C.

Personal Experience of a nearby Earthquake

An earthquake close at hand is rare enough for personal impressions to be of interest. Mr. D. W. Rosebrugh sends the following account.

On December 13, 1944, at 11.15 p.m. (E.W.T.) a mild earthquake or temblor occurred with its epicentre at Wallingford, Conn., about 12 miles E.S.E. from the writer's residence in Waterbury, Conn.

The evening was clear, cold and windless and the writer had just completed his variable star observing for the evening and had retired to bed. A loud

"thunderclap" startled him and in the ensuing silence he had just time to reflect that perhaps it was not thunder, when sounds as of an approaching tremendous "gust of wind" were heard, and he concluded that some freak storm of great intensity had suddenly developed.

Three months earlier, on September 14, Waterbury experienced a hurricane with gusts of wind which reached upwards of 90 m.p.h. at the Hartford Weather Bureau, and the approaching earthquake "wind" sounded as of so much greater intensity that the writer feared his house would be blown down. The "gust of wind" seemingly arrived and of course there actually was no wind whatever, but at the moment of arrival the windows rattled and there was perhaps the slightest perceptible shake of the bed. At this point the phenomenon was identified as an earthquake based on the writer's recollections of a milder earthquake which shook Toronto in, he believes, February 1925.

The noise quickly subsided and a heavy rumbling as of a passing truck faded into the distance. It was perhaps 30 seconds from the first thunderous sound, which however did not re-echo as a thunderpeal usually does, until the rumbling died away.

Hundreds of the inhabitants of Waterbury were disturbed by the earthquake. Most of them apparently thought that some catastrophe had occurred in the cellar, such as the destruction of the furnace by an explosion, but to the writer the noises seemed definitely to approach from a southerly direction and to recede into the earth. Dogs were roused by the phenomena and barked outside for some time, though some retired into their kennels in fear. Apparently no damage of consequence was done by the temblor. C. A. C.

A "Sickle" Moon Rising in the East

Time: Shrove Tuesday.

Place: A rock on the Blasket, an island off the extreme south-west of Ireland, and facing east.

Writer: Maurice O'Sullivan in "Twenty Years A-Growing" (Chap. 17).

It was a fine evening. I was sitting on a rock overlooking the sea. There was a light breeze from the east, frost on the ground, hooded crows flying across the fields with a caw-caw, thrushes, blackbirds and starlings singing sweetly in the meadows; and if you turned your eyes seaward, herring gulls and black-backed gulls diving into the water and a sea-raven among them pursuing small fish. Out before me were Mount Brandon, Mount Eagle and the Macgillycuddy Reeks, clear of all vapour and mist.

It was a lovely sight, praise on high to God who made heaven and earth, and I fell thinking of all the happy days I had spent in the view of those hills and recalled the words of my grandfather: Twenty years a-growing, twenty years in bloom, twenty years a-stooping and twenty years declining.

Night was falling. I walked up from the cliff's edge a little way and sat down. As I looked out again to Mount Eagle I saw a sickle of gold climbing up

behind the hill. The moon was rising. She ascends very slowly and sheds a golden light over the shadowy glens. I seem to hear the meads and valleys utter a cry of joy as if to welcome her and she smiling down on them with a greeting to Corcagueeny. I seem to see before me, full of bright laughter, all the boys and girls who were with me when I was a child. I see them running down the lanes and hiding themselves—the game we used to play in the moonlight—and I hear old Paddy crying in the distance "Caught!" . . . I arise and walk slowly towards the house.

Unfortunately there is not room here for further quotation, but the author's faulty astronomy will not prevent any astronomer from enjoying this charming description and many others in the book. C. A. C.

THE BRIGHT PLANET VENUS

Query

For some weeks I have been interested in a large star that shines very brightly in the southwest-by-west. To-night it set around 8.22. In my lifetime it never before appeared so prominently conspicuous. It appears double as large as any other planet in the sky and more reddish in colour. If there were many like it we would not need any moon. It seems to journey and set far quicker than sun or moon.

GEORGE ROBB

Fort Qu'Appelle, Sask., Dec. 23, 1944.

Answer

The bright object referred to is the planet Venus. Its orbit is within that of the earth and its revolution period about the sun is 225 days. As a consequence its movements in the sky and its variations in brightness are not easy to follow. It has a reddish colour when near the horizon. On February 2 Venus reaches its greatest distance east of the sun, namely 47 degrees. In the telescope it then looks like a half-moon. It increases in brightness until March 10. (For further information reference may be made to the OBSERVER'S HANDBOOK published by the Royal Astronomical Society of Canada, 198 College St., Toronto, 25c postpaid.)

C. A. C.

BANDS TRAVELLING ACROSS THE CLOUDS

This peculiar phenomenon was referred to in Notes and Queries for October and December last. It may be stated that it is discussed in "Nature" for Sept. 30, and Dec. 9, 1944. C. A. C.

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